IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 08, Issue 8 (August. 2018), ||V (I) || 33-42

Groundwater Quality Assessment in Srikalahasthi Mandal, Chittoor District, Andhra Pradesh, South India.

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Abstract: The present study aimed to assess the groundwater quality in Sri Kalahasthi Mandal, Chittoor District of Andhra Pradesh State. A total number of 40 groundwater samples were collected from various parts of the study area during pre-monsoon period (May-2017) to evaluate its parameters such as (pH), EC, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Sulphate (SO_4^{2-}), Chloride (Cl^{-}), and Bicarbonate ($HCO3^{-}$). The results indicate that these parameters are spatially inhomogeneous and the groundwater samples can be classified to be Na-Cl and Mixed Ca-Na-HCO3 types. Moreover, Gibbs diagram suggest that precipitation dominance is the main process controlling the hydrochemistry of the groundwater in the study area. In association with WHO standards, the majority of the groundwater samples can meet up the requirement for drinking with few exceptions. In the study area, elevated concentrations of chlorides and sulphates serve as indicators of groundwater pollution due to the local anthropogenic contamination by septic tanks, sewage systems, and agricultural fertilizers. Moreover, the suitability of groundwater for irrigation was determined according to the sodium absorption ratio (SAR), percentage sodium (% Na) and permeability index (PI), residual sodium carbonate (RSC), Kelly's ratio and magnesium ratio. The study has been concluded that the water from the study area is suitable and irrigation with few exceptions.

Keywords; Groundwater quality, Drinking purposes, Irrigation, Physico-chemical parameters, Hydrochemical facies, Srikalahasti Mandal

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Date of Submission: 20-07-2018 Date of acceptance: 04-08-2018

I. INTRODUCTION

Nowadays groundwater plays more and more important role in the development and management of water resources. Moreover, the issue of groundwater has become a strategic issue for a number of countries including India for usage owing to the deterioration of quantity and quality of surface water resources. Many aspects of water quantity and quality are closely interlinked. Water quality can vary in importance depending on the actual water quantity and the dilution rate (Arthington et al. 2010). In general, India is a groundwater-dependent nation. Even at conservative estimates, 85% of rural drinking water in India is derived from wells (The World Bank, 2010). With nearly 88% of the total annual groundwater drawn from all the wells in India being used for irrigation (IDFC Foundation, 2013), we estimate that nearly 700 million Indians who live in Indian villages, almost entirely depend upon groundwater for their daily needs (Kulkarni et. al 2015). Prospective studies reveal that the country's water demand is projected to reach 784–843 km3 by 2025 and 973–1180 km3 by 2050 (Ministry of Water Resources, 2000). Recent investigations predict that, if the demand-supply gap amplifies, nine basins that have over four-fifths of the total water use in India will face physical water scarcity by 2050 (Amarasinghe et al., 2007a). These signs, which are already visible in a few regions around India, are soon to assume a nationwide proportion and may become a permanent feature of the water sector in the country, unless suitable policies are adopted quickly to manage water demand and supply at different levels (Rathinasamy Maria Saleth, 2011). Earlier so many researchers have worked on this issue (Anke Kirch, 2002; Vijay Kumar et al. 2006; Palmer et al. 2007; Petts, 2009; Chen et al. 2012; Chen et al. 2013; Ming Dou et al. 2016:Nagaraju et al .2017 and Getahun and Keefer 2016)

Indeed, the study area is currently facing water shortages due to its semi-arid terrain, crystalline basement and the geographic distortion between water-producing and water-consuming areas. In addition to this, the deterioration of water reserves caused by the increase in the number of sources of pollution is now a reality. In the study area, no previous works were carried out in order to know the suitability of groundwater for drinking and irrigation purposes. Hence, an attempt has been made in order to avert possible devastating effect such as livelihood fronts, agriculture and soaring contaminant levels are threatening this meagre supply too. It is, therefore, essential to have a proper understanding of the hydrochemical characterization of groundwater in such terrain since water quality is as important as the quantity.

II. STUDY AREA

Geographically the study area lies between 13°39'7.2"N and 13°55'26.4" N latitudes and 79°26'2.4"E and 79°42'50.4"E longitudes and covers a total area of about 407.36 sq.km. (Figure. 1). The area has a semi-arid climate, which is characterized by hot summer and cold winter. December is the coldest month of the year with the mean maximum and minimum temperature of 30.1°C and 19.9°C respectively. May is the hottest month with a mean maximum temperature of 34.8°C and minimum of 23.9°C. The average annual rainfall of mandal is about 959.6 mm and the mandal receives seasonal rainfall in both southwest and northeast monsoon periods. The eastern plain receives high rainfall during northeast monsoon period due to low pressure forming in the Bay of Bengal. Geologically rocks of Archaean, Proterozoic, tertiary and quaternary ages are exposed in the study area. The formations chiefly composed of a complex assemblage of gneissic variants, granitic rocks with dolerite intrusive, Nagari quartzite's, isolated laterite patches, Cuddapah formations such Bairenkonda quartzites, Pullampeta shales, slates and recent alluvium deposits.

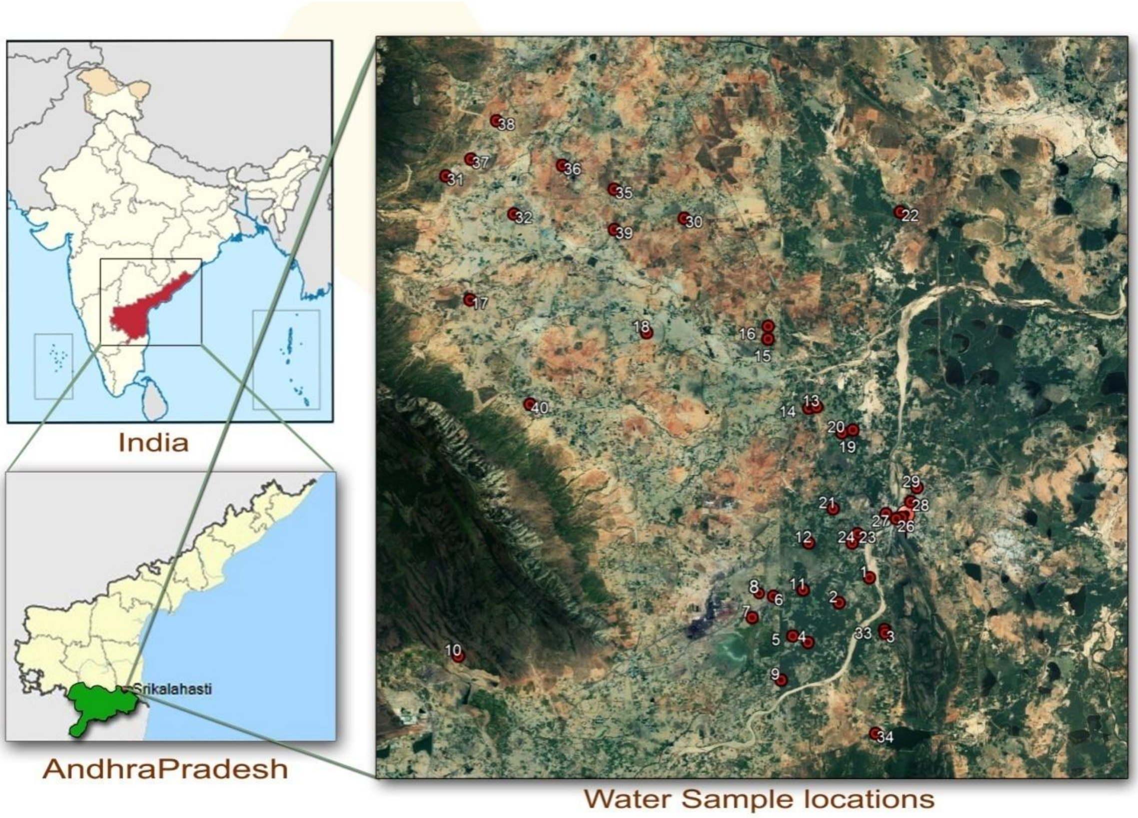

Figure 1. Location map of the study area with water sample locations

III. MATERIALS AND METHODS

The samples were collected in one liter pre-washed high-density polyethylene bottles and also rinsed with actual water samples at each bore well before collecting. Precaution was taken to avoid sample leakage during transport to the laboratory. A total of 40 representative groundwater samples were collected during pre-monsoon period (May-2017) with in-situ measurement of pH and Electrical Conductivity (EC) using portable water analysis kit (P-30 Series Hand-held Water Quality Meters for pH and conductivity-Analyticon Instruments Corporation, USA). Then samples were analyzed for cations and anions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, and SO_4^{2-} , by using the analytical procedures suggested by the Trivedy and Geol 1986; APHA 2005; Mishra et al. 2012; Tripathi et al. 2012). The minimum, maximum and average values of different constituents of water samples are depicted in (Table1).

Table 1. Minimum, maximum, average and suitability categorization for drinking according to WHO guide lines of different constituents of water samples (mg/l)

S. No.	Constituents	Min	Max	Average	MPL	SEMPL
1	Calcium (Ca)	19	108	53	200	0
2	Magnesium (Mg)	7	68	31	150	0
3	Sodium (Na)	81	266	148	200	4
4	Potassium (K)	2	12	5	NG	-
5	Bicarbonate (HCO3)	429	859	598	NG	-
6	Sulphate (SO4)	264	3606	487	250	40
7	Chloride (Cl)	202	2355	778	250	38
8	Specific conductance (µmhos/cm)	66	950	140	NG	-
9	pH	6.80	8.10	7.42	6.5-8.5	0
	* Minimum, maximum, average and suitability categorization for rating water quality for irrigation purposes of different constituents of water samples (meq/l)					
10	Sodium adsorption ratio (SAR)	2.07	9.28	4.11	>26	0
11	Percent sodium	34.56	79.50	53.39	>80	0
12	Potential salinity	10.20	70.15	27.01	>10	40
13	Residual sodium carbonate	0.50	9.07	4.51	>2.5	33
14	Kelly's Ratio	0.52	3.84	1.34	>1	28
15	Mg Ratio	17.57	73.81	49.32	>50	18
16	Permeability Index	60.16	104.36	82.56	>75	30
17	Non-carbonate hardness	-453.69	-25.08	-225.56	-	-
18	Indices of Base exchange – I	-0.23	0.92	0.56	-	-
19	Indices of Base exchange – II	-0.06	4.07	0.84	-	-
20	Gibbs ratio I	0.32	0.90	0.64	-	-
21	Gibbs ratio II	0.50	0.89	0.71	-	-

* According to Ayers and Westcot (1985), Eaton (1950), Todd (1980), Wilcox (1950) Doneen (1964) and Kelly (1940; 1963) respectively

IV. RESULTS AND DISCUSSION

Water quality characteristics for drinking purposes

The physico-chemical parameters of the groundwater samples were analyzed statistically and the minimum, maximum and mean concentrations are summarized in (Table 1).

In the study area, the minimum and maximum values of pH and electrical conductivity (EC) of are ranging from 6.80 to 8.10 and 66 to 950µmhos/cm, respectively. The Concentrations of Na^+ and K^+ in groundwater samples are in the range of 81 to 266 and 2 to 12 mg/l, respectively. The concentrations of Ca^{2+} and Mg^{2+} are in the range from 19 to 108 mg/l and 7 to 68 mg/l respectively. The concentrations of $HCO3^-$ ions are ranged from 429 to 859. The concentration of Cl^- and SO_4^{2-} are in the range from 202 to 2355 mg/l and 264 to 3606 mg/l respectively. The abundance of the major ions in groundwater is in following order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > HCO_3^- > SO_4^{2-}$

The permissible limits of analyzed ions and the number of groundwater samples exceeding permissible limits were tabulated in Table 1 in compliance with WHO (2011)

Water quality characteristics for irrigation purposes

Sodium Adsorption Ratio (SAR):

SAR is the most commonly used to assess the suitability of irrigation water.

It measures sodicity in terms of the relative concentration of sodium ions to the sum of calcium and magnesium ions in a water sample. Excess sodium concentration can reduce the soil permeability and soil structure (Todd, 1995).

SAR is calculated using the following formula:

$$SAR = Na+ / \surd (Ca^{2+} + Mg^{2+}/2)$$

Where the ionic concentrations are expressed in meq/l.

The calculated value of SAR in this area ranges from 2.07 to 9.28 meq/l. (Table 1).All the samples were within permissible limits (<10). The US Salinity Laboratory's diagram is widely used for evaluation irrigation water where SAR is plotted against EC (Richards 1954). The SAR values plotted against EC values of the water samples of the study area shows that the majority of the water samples (about 99%) falls under C1S1(low salinity-low sodium hazard) zone except one falls under C3S1(high salinity-low sodium hazard) zone (Figure2)

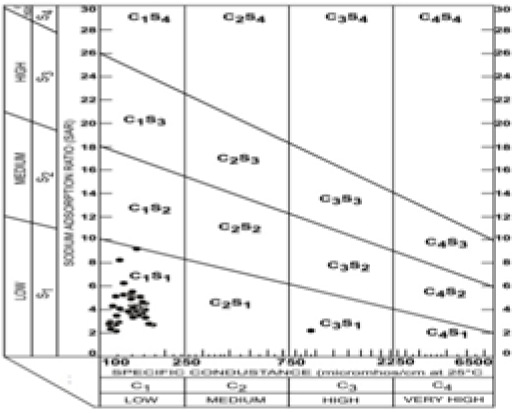

Figure 2. The quality of groundwater samples in relation to salinityand sodium hazard

Percentage Sodium (% Na):

Percent sodium is a key parameter for determining the suitability of water for irrigation purposes. High percentage sodium water for irrigation purpose may inhibit the plant growth and reduces soil permeability (Todd, 1980). Na% which was calculated from the formula given in equation and all concentrations were expressed in meq/l.

$$\%Na^+ = (Na^+ + K^+) X 100 / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$$

The calculated percent sodium values in this area ranges from 34.56 to 79.50 meq/l. (Table 1).Wilcox's diagram (1948) is principally implemented to classify suitability of water for irrigation. (Figure 3) shows that all the water samples (39) fall under excellent to good category and the remaining one falls under good to a permissible category.

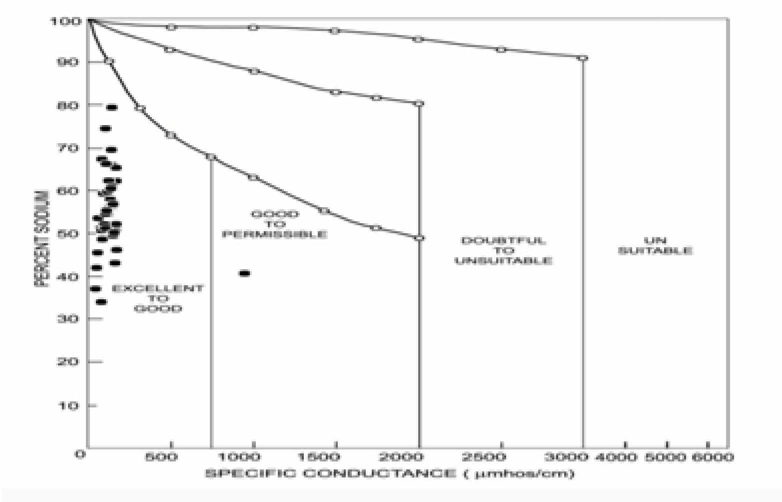

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Figure 3. The quality of groundwater in relation to electrical conductivity and percent sodium

Magnesium Hazard

In general, Ca and Mg retain a state of equilibrium in most waters. Excess Mg in waters unfavourably affects the crop yield. In this study magnesium hazard was assessed by the following formula

$$Mg\ Ratio = [Mg/ (Ca + Mg)] \times 100$$

The values varied from 17.57 to 73.81 with an average value of 49.32 meq/l. In this study, nearly 51% of the groundwater samples have >50% (Figure 4) magnesium ratio values, would adversely affect the crop yield as turn the soils more alkaline (Ayers and Westcot, 1985)

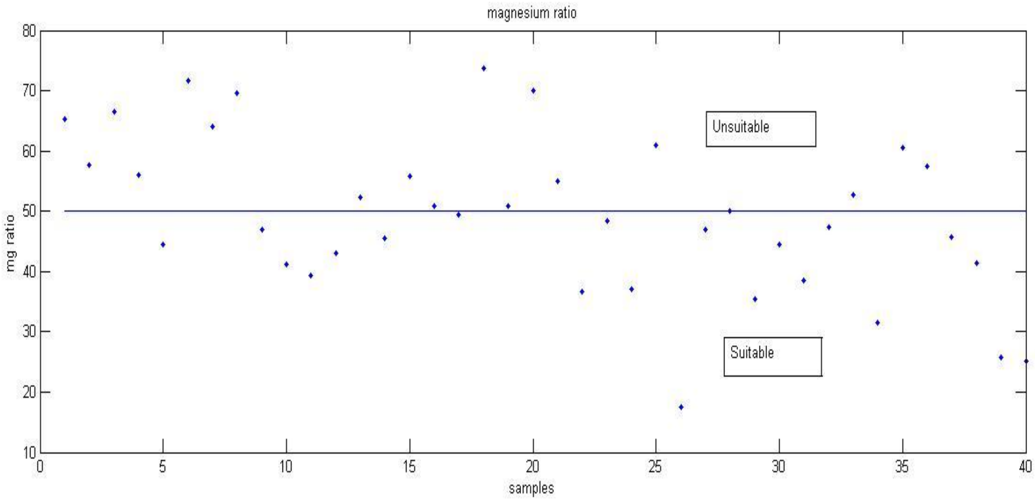

Figure 4. Magnesium ratio

Non-Carbonate Hardness (NCH)

The hardness of water relates to the reaction with soap, since Ca and Mg ions precipitate soap. Hardness is expressed as mg/l of $CaCO_3$. If the hardness as $CaCO_3$ exceeds the difference between the alkalinity as $CaCO_3$ and hardness as $CaCO_3$, it is termed as Non-Carbonate Hardness (Balaji et al. 2017; Nagaraju et al. 2014). NCH is also called permanent hardness. The NCH values ranged from 453.69 to -25.03 with an average of -225.56 meq/l.(Table.1)

Kellys Ratio

Kelly (1940; 1963) has found the hazardous effect of sodium on water quality for irrigation usage in terms of Kelly's ratio (KR). Kelly's ratio was calculated from the formula given in equation and all concentrations were expressed in meq/l.

$$Na^{+} / (Ca^{2+} + Mg^{2+})$$

The values varied from 0.52 to 3.84meq/l. with an average value of 1.34. Kelly's ratio of >1 indicates excessive sodium in water. Therefore, water with Kelly's ratio <1 are suitable for irrigation, while those with a ratio >1 are unsuitable. In the present study, 50 % of the groundwater samples are unsuitable for irrigation with >1 of Kelly's ratio (Figure 5).

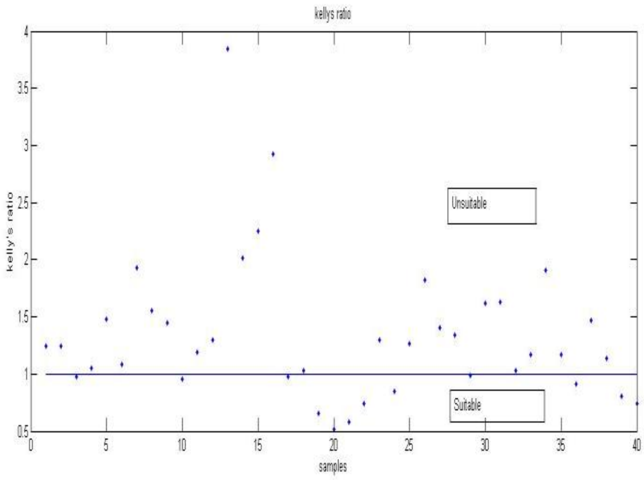

Figure 5. Kelly's ratio

Residual sodium carbonate (RSC)

Residual sodium carbonate (RSC) is determined to find out the hazardous effects of carbonate and bicarbonate on the quality of water used for irrigation purposes (Raju 2007). The residual sodium carbonate is changing their quality of water through the precipitation of alkali earth elements (Ca^{2+}, Mg^{2+}) thereby increasing the percentage of Na^{+} (Eaton 1950). The suitability of RSC value for irrigation is 1.25meq/l. The higher concentration of RSC may lead to the poor quality of soil for irrigation. The RSC values range from 0.50

to 9.07 meq/l. Based on the value of the RSC, all the samples are unsuitable for irrigation purposes, excepting few (Sample no 21, 35, 38, and 40) (Figure 6)

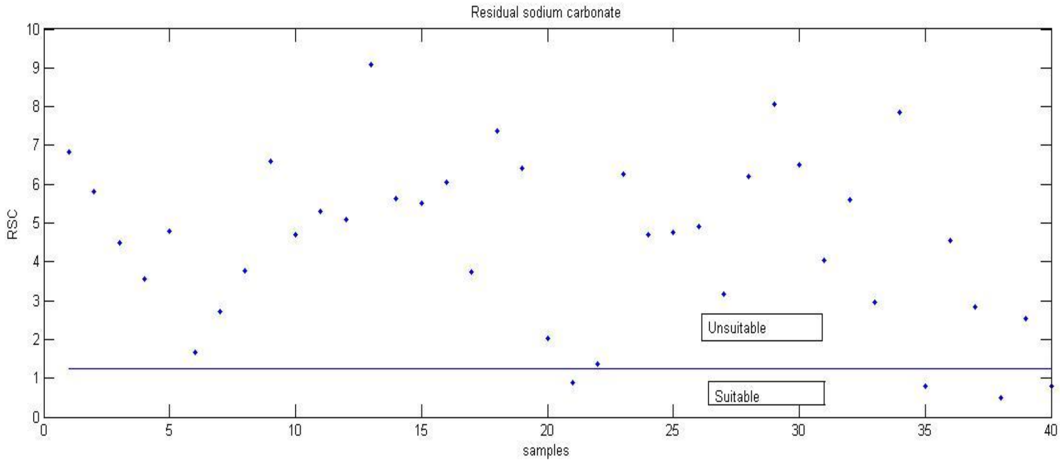

Figure 6. Residual sodium carbonate

Permeability Index (PI)

Permeability index (PI) is a vital parameter to assess the quality of irrigation water in relation to the soil for improvement in agriculture (Thilagavathi et al. 2012; Thivya et al. 2013a). The long-term use of irrigation water can affect the soil permeability, influenced by the Na^+, Ca^{2+}, Mg^{2+}, and $HCO3^-$ contents of the soil. Permeability Index is calculated by using the following formula;

$$PI = 100\times (Na^{+} + \sqrt{HCO3^{-}}) / (Ca^{2+} + Mg^{2+} + Na^{+}), \text{ unit in meq/l.}$$

Based on the PI values, the irrigated water can be classified as Class I (>75 %), Class II (25–75 %) and Class III (<25 %). The PI values of the study area are in the ranges from 60.16 to 104.36meq/l.. Nearly 80 % of the samples are fall under Class I category and another 30 % of the samples belong to the Class II category indicating that the water is moderate to good for irrigation purposes(Figure 7).

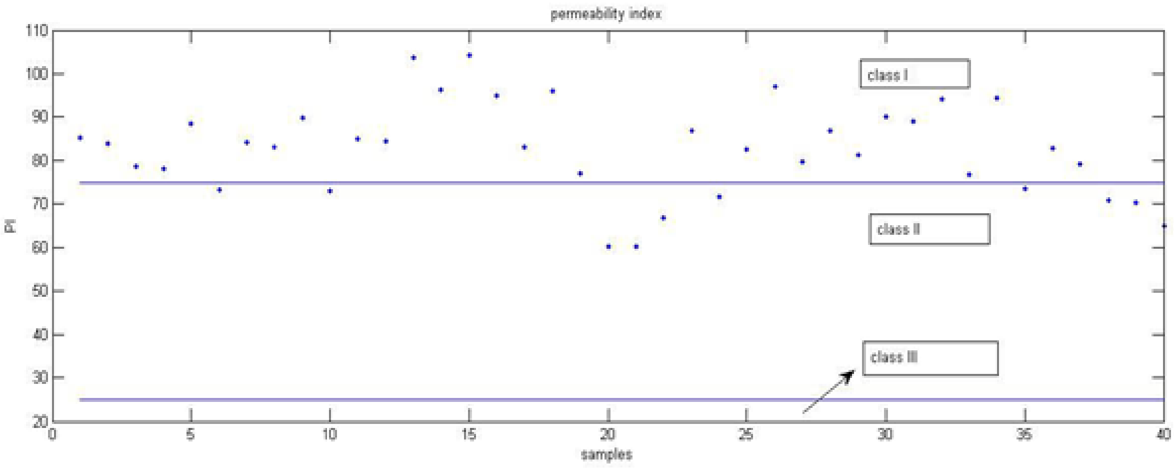

Figure 7. Permeability Index

Potential salinity

Doneen (1964) elucidated that the suitability of water for irrigation is not dependent on soluble salts. Because, the low solubility salts precipitate and accumulate in the soil with successive irrigation, the concentration of highly soluble salts increases the soil salinity. Potential salinity is calculated from the following formula

$$PS = Cl^{-} + ½ SO_4^{2-}, \text{ unit in meq/1 .}$$

The potential salinity of the water samples is in the range from 10.20 to 70.50meq/l. It suggests that the potential salinity in all the groundwater samples of the studied area nearly is high (>10), thus, making the water unsuitable for irrigation usage (Figure 8).

Minimum, maximum, average and suitability categorization for rating ground water quality for irrigation purposes of different constituents of water samples according to Ayers and Westcot (1985), Eaton (1950), Todd (1980), Wilcox (1950) Doneen (1964) and Kelly (1940;1963) respectively are depicted in Table 1.

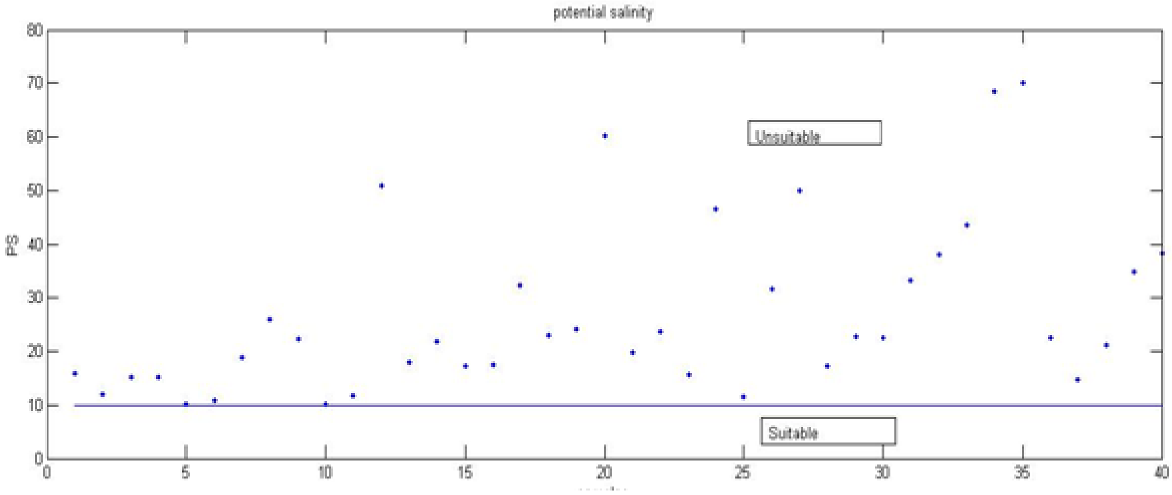

Figure 8.Potential salinity

Chloroalkaline indices

Chloroalkaline indices I and II are employed to know the chemical reactions in which ion exchange takes place (Swarna Latha and Nageswara Rao 2012). It shows positive values when there is an exchange of Na and K from the water with Mg and Ca of the rocks, while the negative shows when there is an exchange of Mg and Ca of the waters with Na and K of the rocks. In this study, the CAI 1 values range from -0.23 to 0.92 and CAI 2 values varies from -0.32 to 4.07. From these values, it can be interpreted that some of the samples in the study area fall into negative zones and some fall into positive zones (Figure 9).

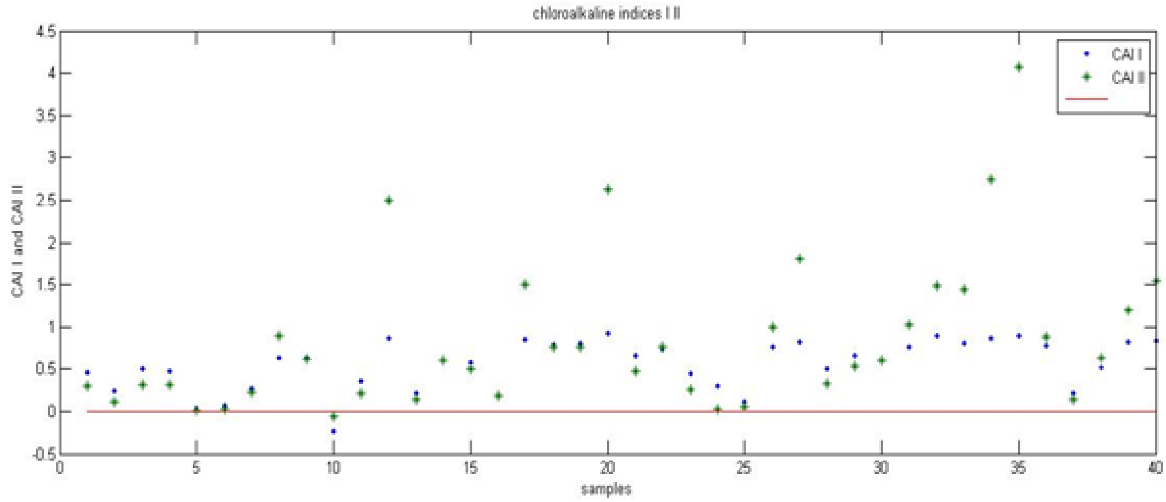

Figure 9. Chloroalkaline Indices

Hydrochemical facies

A Piper plot is constructed from two ternary diagrams, one of the major cations on the left and one of the major anions on the right (Piper 1944 and 1953). The points on the two ternary diagrams are projected upward to a diamond diagram. This diagram is used to evaluate the hydrogeochemical characteristics of Srikalahasti area (Figure 10). The plot shows that most of the groundwater samples (80%) are falling in the field of Na-Cl type and (18%) of samples falling in the field of mixed Ca-Na- HCO3 type and the remaining one sample falling in the field of Ca-Cl type. This process suggests that there is a clear indication that alkalis (Na^{+}+K^{+}) and strong acids (Cl^{-}+SO_4^{2-}) dominated over the alkaline earth (Ca^{2+}+Mg^{2+}) and weak acids (CO_3^{2-}+ HCO_3-). The elevated Na^{+} concentrations coupled to low Ca^{2+} suggesting that Ca^{2+} and Na^{+} ion exchange process is an important geochemical process for the Na–Cl type of groundwater.

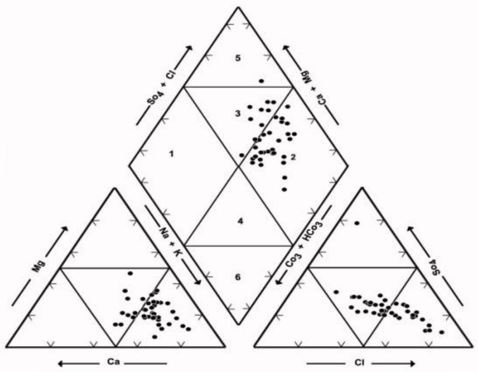

Figure 10. Trilinear diagram for representing the analyses of groundwater quality (Piper diagram)

Mechanisms controlling groundwater hydrochemistry

Gibbs diagram

Gibbs diagram is employed to interpret the effect of hydro geochemical processes such as precipitation, rock-water interaction mechanism and evaporation on groundwater geochemistry. The reaction between groundwater and aquifer minerals has a considerable role in groundwater quality which is useful to assume the genesis of water. Gibbs ratio is calculated by using the following equation (Gibbs, 1970).Gibbs ratio I = $(Cl^- / Cl^- + HCO_3^-)$

Gibbs ratio II = $(Na^+ + K^+)/(Na^+ + K^+ + Ca^{2+})$

In the present study, Gibbs ratio I values varied from 0.32 to 0.90 and Gibbs ratio II values varied from 0.50 to 0.89 (Table 1). From (Figure 11), it is clear that 37 samples are falling under precipitation dominance area and the remaining samples falling under rock dominance category. This indicates that the precipitation dominance plays an important role in controlling the groundwater chemistry of this area.

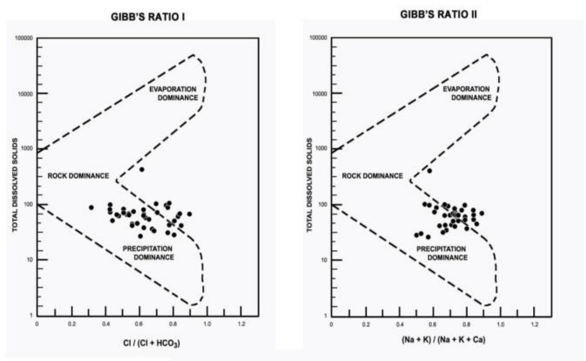

Figure 11. Gibbs diagram

V. CONCLUSION

The study reveals that the groundwater in Srikalahasti region is fresh in nature. The order of the abundance of the major ions in groundwaters of the study area is as follows $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > HCO_3^- > SO_4^{2-}$. The piper trilinear diagram shows that the dominant groundwater type was Na-Cl and mixed Ca-Na-HCO3. Moreover, Gibbs diagram suggest that precipitation dominance is the main process controlling the hydrochemistry of the groundwater in the study area. The USSL diagram reveals that almost all the samples fall in a C1-S1 zone indicates low salinity and low-sodium except one falls in C3-S1 zone indicate high salinity and low sodium hazard. Wilcox diagram reveals that out of 40 samples, 39 samples fall under excellent to good category and one falls under good to a permissible category. In comparison with standards from WHO (2011), the majority parameters were found to be within permissible limits for drinking with few exceptions such as chlorides and sulphates from anthropogenic sources. In addition, SAR, percent Na, RSC, PI, KR, and MR suggest that all the groundwater samples are suitable for irrigation with few exceptions.

ACKNOWLEDGEMENTS

The first author M. Subbarao is thankful to the Rajiv Gandhi National Fellowship, University Grants Commission, New Delhi for providing the Junior Research Fellowship (F1-17.1/2016-17/RGNF-2015-17-SC-AND-18257/ (SA-III/Website).

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